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Electrophysiological Correlates of Time-based Prospective Memory Across the Lifespan

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ELECTROPHYSIOLOGICAL CORRELATES OF TIME-BASED PROSPECTIVE MEMORY IN INDIVIDUALS ACRROSS THE LIFESPAN

BY

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Abstract

This study investigated the electrophysiological correlates of time-based prospective memory (PM) in individuals in two different age groups using a clinical measure of time-based PM and a computerized paradigm (Cona et al., 2012). PM involves the ability to form and realize intentions after a time delay (Einstein & McDaniel, 1990). The clinical measure of PM used was the Memory for Intentions Screening Test (MIST), which assessed both time- and event-related PM. These results were compared with average amplitude of the event-related potentials (ERPs) in response to 2- and 5-minute PM tasks at four different post-stimulus time intervals and behavioral data collected while participants completed a computer-based PM task that assessed time-based PM. Older adults performed significantly worse on MIST tasks with a 15-minute time delay, event-based cues, and action-based responses. Their total MIST scores were also significantly lower than younger adults. They also made more PM errors and total errors and scored lower on retrospective recognition. On the computerized-PM tasks, older adults performed significantly worse on PM tasks with a 5-minute time delay. ERP data was significantly different between groups only on 5-minute delay PM trials in which the PM task was successfully completed. In the 275-325 milliseconds (ms) post-stimulus time window, older adults had significantly higher amplitudes in left frontal electrodes and significantly reduced amplitudes in right parietal and occipital electrodes suggesting their frontal lobes work harder in maintaining the intention. The reduction in the occipital electrode was the only ERP difference that extended into the 550-600 ms post-stimulus time window, a period critical for cue detection. Previously Cona et al. (2012) found a similar pattern in event-based PM (rather than time-based), possibly indicating that the presence of a separate clock altered the nature of the time-based cue into more of an event-based cue. Overall, this study found older adults to have significantly worse PM performance, particularly on tasks where the time-delay was greater than two minutes and that their ERP differences on correctly realized 5-minute PM tasks were significantly different from younger adults on frontal and parietal electrodes in the time period critical for strategic monitoring.

Introduction

The present study aims to investigate the electrophysiological correlates of time-based prospective memory (PM) in individuals from early to late adulthood to provide a better understanding of the role of aging in PM. In 2050 the number of senior citizens in the United States is projected to be almost double what it was in 2012 (U.S. Census Bureau, 2014). While there has been significant research demonstrating declines in retrospective memory with age, another impairment often associated with age is poor PM performance, or trouble remembering to carry out a future intention (Henry et al., 2004).

Prospective Memory

PM is the ability to remember to carry out a future intention after a time-delay (McDaniel & Einstein, 2000). Everyday life involves many examples of PM, including critical tasks such as remembering to take your medications as scheduled, remembering to pick up your children at school, and remembering to give a friend a message. There are currently believed to be at least five phases involved in PM: intention formation, a delay period where the intention cannot be realized, a performance interval where the intention should be realized, realization of the intention during the performance interval, and monitoring success or failure (West & Ross-Munroe, 2002).

Additionally, PM has been divided into two types: event-based PM and time-based PM. Time-based PM is when an individual must remember to perform the designated action at a specific time, while event-based PM occurs when an individual must remember to perform the designated action in response to a specific event (Einstein & McDaniel, 1990). For example, remembering to take your medication at 7 AM is a time-based PM task, whereas remembering to take your medication after breakfast is an event-based PM task. In time-based PM the cue is internal and event-based PM the cue is external (Cona et al., 2012). Furthermore, previous research has shown differences in performance in healthy adults (HA) on a comparison between event-based PM tasks and time-based PM tasks, with time-based PM tasks being more difficult to perform (Koriat et al., 1990).

There are two competing theories of PM: McDaniel and Einstein's (2002) multi-process framework and Smith and Bayen's (2004) preparatory attentional processes and memory processes (PAM) model. The multi-process framework theory of PM states that people use multiple approaches when retrieving an intention. Individuals monitor the environment for the appearance of the target event as well as rely on anticipated environmental conditions to reinstate the intended action. The multi-process theory states that both voluntary and involuntary actions are used to retrieve PM cues from the environment. There is a strategic aspect in switching attention from the ongoing task as well as an involuntary automatic response to the PM target. Einstein and McDaniel (2002) also propose that the method used depends on factors including: the importance of the PM task, the nature of the cues and their relation to the intended action, the nature and constraints of the ongoing task, and individual differences in both cognitive and personality variables.

The PAM model proposed by Smith and Bayen (2004) is specific to event-based PM. According to the PAM model of PM, the prospective component involves processes that take into account the available resources and, thus, are not automatic. In order to successfully complete an event-based PM task, the individual must employ capacity-consuming preparatory processes along with retrospective memory processes. PAM states that all successful PM tasks require resource-demanding preparatory attentional processes.

In summary, the PAM model assumes that once an intention is formed, an individual is constantly scanning the environment for a cue and preparing for retrieval. In contrast, the multi-process theory states that individuals process the cue when it arrives and the processing depends on a multitude of factors. The key difference between the two models is that in the multi-process theory no preparatory attention is necessary to realize the cue (Einstein and McDaniel, 2010).

The two generally accepted clinical assessments of PM are the Cambridge Test of Prospective Memory (CAMPROMPT) (Fleming et al., 2008) and the Memory for Intentions Screening Test (MIST) (Raskin, 2009). The CAMPROMPT requires individuals to perform three time-based and three event-based tasks while performing an ongoing task involving both written and verbal instructions. Individuals are allowed to use strategies, such as note taking, to help them remember the tasks they need to complete. The CAMPROMPT is scored on an 18-point scale based on subscores on time- and event-based tasks, with higher scores indicating better PM performance (Fleming et al., 2008).

The MIST was created by Raskin (2004) and is another assessment of PM. The MIST is similar to the CAMPROMPT in that each involves time- and event-based tasks as well as an ongoing distractor task. In the MIST, however, individuals are not permitted to take notes or write down reminders. The MIST involves both verbal and action responses after short delays of two minutes and long delays of fifteen minutes. There is also a multiple-choice section examining retrospective recognition and a more naturalistic 24-hour delay. The types of error codes on the MIST include: prospective memory failure (PF), task substitution (TS), loss of content (LC), loss of time (LT), loss of place (LP), and random errors (RE). The MIST provides a clinical measure of event- and time-based PM tasks which can then be compared to this study's computerized time-based tasks. Since EEG studies (Cona et al., 2012, West and Ross-Munroe, 2002) have been simplistic in nature, the MIST allows investigation into event- and time-based PM that mirrors daily life tasks.

Brain Regions Associated with Prospective Memory

Multiple studies have aimed to determine the specific brain regions that are associated with PM. A variety of techniques including positron emission tomography (PET) (Burgess et al., 2001; Burgess et al., 2003), functional magnetic resonance imaging (fMRI) (Simons et al., 2006) and magnetoencephalography (MEG) (Martin et al., 2007) have been used to identify the specific regions important in the different steps of PM. PET studies found significant decreases in regional cerebral blood flow in the polar and superior rostral aspects of the frontal lobes, particularly in Brodmann's area 10 (BA 10) during PM conditions compared with the ongoing task, the activity participants are engaged in during the delay between PM cues. Conversely, the more lateral areas showed increases in regional cerebral blood flow during PM tasks. Thus, Burgess et al. (2003) suggested that the medial rostral prefrontal cortex is important in suppressing internally-generated thoughts, while the lateral rostral prefrontal cortex is important in maintaining the thought. A 2006 study by Simons et al. showed similar findings supporting the hypothesis that BA 10 is important to detect the cue while performing the ongoing task. Cue identification and intention retrieval also share a common neural basis, BA 10. Current evidence indicates that the frontal lobe is critical in all aspects of PM with other areas being involved for more specific aspects. Specifically, each of BA 10, the right lateral prefrontal cortex, interior parietal lobe, and precuneaus of the superior parietal lobe are activated while an individual is maintaining an intention (Simons et al., 2006).

A disproportionate amount of the research to date, however, has focused specifically on event-based PM. Nevertheless, a few studies using both PET technology (Okuda et al., 2007) and fMRI (Oksanen et al., 2014) have highlighted some time-based PM findings. A 2007 study conducted by Okuda et al. used PET technology to determine if there were different neural mechanisms associated with the different types of PM. The time-based PM condition was further subdivided into two conditions, one in which participants responded to time-based PM cues based on their own estimation of time and another where they had a clock available. Okuda et al. (2007) found differential activation in the rostral prefrontal cortex depending on the time of PM task. In the time-based PM condition where individuals had to estimate time, the most active area was the left superior frontal gyrus. Alternatively, in the time-based PM conditions where individuals had a clock to monitor time, three rostral prefrontal regions, the right superior frontal gyrus, anterior medial frontal lobe, and anterior cingulate gyrus were most active. In the event-based PM condition, an additional region in the left superior frontal gyrus was found to be most active. Thus, this study indicates that different brain regions are associated with time-based PM tasks as compared with event-based PM tasks. Furthermore, the brain regions associated with time-based PM depend on whether or not the individual is estimating time or not.

Another study conducted by Oksanen, Waldum, McDaniel, and Braver in 2014 studied the neural mechanisms specifically for time-based prospective memory using fMRI technology. Participants were all otherwise healthy young adults ranging in age from 19-36. The PM task was embedded in the 2-back version of the N-back working memory paradigm. In the PM condition, participants also had the ability to hit two additional buttons, one to show a clock revealing the exact time elapsed and another representing the PM task. Participants were instructed to hit a fourth button either exactly every three or four minutes. Additionally, to control for the clock, pseudo-clock information was presented intermittently in the control condition that was irrelevant to the task (Oksanen et al., 2014). All participants completed eight scanning runs, consisting of four control and four time-based PM runs. The PM scanning runs were evenly divided between 3- and 4-minute duration runs. Accuracy was measured according to both a 6-second and 20-second interval (Oksanen et al., 2014). Behavioral results indicated that clock-checking frequency was positively correlated with PM accuracy. However, clock-checking frequency was not correlated with fMRI activity. Results also did not show a performance cost during the PM task blocks indicating that time-based PM may not involve sustained monitoring as hypothesized (Oksanen et al., 2014). Additionally no difference in activation of the anterior prefrontal cortex (aPFC) was found between time-based PM and control tasks. The regions of the brain found to have been activated pre-clock in the time-based PM condition were all part of the same dorsal frontoparietal network that was previously shown to have been engaged by attentional control and monitoring processes (Corbetta & Shulman, 2002). Conversely, only weak activation was seen in the same aPFC regions of interest in response to PM targets. These results demonstrate that there are different neural mechanism in time-based PM compared with event-based PM as they showed no sustained activation of the aPFC. This region was only activated in anticipation of a time-based PM cue, and not as strongly as the activation of the pre-Supplementary

Motor Area (Oksanen et al., 2014). In summary, frontal activation, specifically, the right superior frontal gyrus, anterior medial frontal lobe, and anterior cingulate gyrus were most active in time-based PM.

Aging and Prospective Memory

As individuals age, it has been hypothesized that PM tasks are harder to perform compared with retrospective memory tasks given the requirement for self-initiated remembering (Henry et al., 2004). Similarly, time-based PM tasks are believed to be more susceptible to the effects of aging given the self-initiated nature of the cue detection (Einstein et al., 1995; Maylor, 1995). Studies by d'Ydewalle et al. (2001), Einstein et al. (1995), and Park et al. (1997) have all shown age-related deficits in time-based PM. In contrast, more inconsistent results have been seen when studying the effects of age on event-based PM with some studies showing substantial evidence (Cherry et al., 2001; Dobbs & Rule, 1987; Kidder, Park, Hertzog, & Morrell, 1997; Mantyla & Nilsson, 1997; Maylor, 1993, 1996; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997; West & Covell, 2001) and others showing none (Einstein & McDaniel, 1990; Einstein et al., 1995). Studies that compared the two types of PM in the same set of participants have shown that age-related deficits are not only more consistently associated with time-based PM conditions, but also more pronounced in these conditions (Henry et al., 2004).

While most studies demonstrate decreased performance of older individuals on PM tasks compared with their younger counterparts, there is one notable exception: naturalistic time-based PM tasks (Henry et al., 2004). Examples of such tasks include calling the experimenter at specific times over differing periods of time (Devolder at al., 1990; Poon & Schaffer, 1982; Moscovitch, 1982; Maylor, 1990) or mailing a postcard to the experimenter (Patton & Meit, 1993). Older individuals have also been found to be better at remembering to attend appointments (Martin, 1986). A possible explanation for this notable difference, however, may be in the motivation of the participants while outside of the laboratory setting. Older adults have reported having higher numbers of memory failures and more concern about these. Therefore, it has been suggested that older adults have more motivation to accurately perform the given tasks. One strategy employed is the pairing the PM task with a routine event such as taking medicine (Henry et al., 2004). Given the inherent nature of naturalistic PM tasks, such factors are hard to control and may explain why older adults have been shown to perform better on these tasks compared with younger adults.

Electrophysiological Correlates of Prospective Memory

In addition to behavioral and neuroimaging research on PM, a significant amount of research has been done using electroencephalography (EEG) to study the electrophysiological correlates of PM. Event-related potentials (ERPs) are electrical brain responses that result from either an internal or external stimulus and reflect either a positive or negative voltage direction over time (West, 2011). Additionally, ERPs are useful for localizing specific brain regions and activity associated with PM. West and Ross-Munroe (2002) used ERPs to study the five stages of PM: intention formation, a delay period, a performance interval, realization, and monitoring using the partial cue PM task.

West (2011) found that previous research indicated that there was a correlation between distinct components of ERPs and detection of PM cues in the environment, retrieval of intentions from memory, and possibly switching from an ongoing activity to the PM part of the task in order to realize a delayed intention. In addition, West hypothesized that there might be an executive control process that cannot be described using the current theories of PM (West, 2011). Previously, West and Ross-Munroe (2002) claimed that there were three components of ERP that distinguished trials of PM and ongoing activity trials: N2, P3, and frontal slow wave. Out of these three ERPs, the frontal slow wave was the only component to reflect a difference for PM hits than PM misses. This finding is important because it shows there is a difference in the ERPs of a miss, or an unrealized intention, compared with the ongoing task. Thus, this can be interpreted as individuals are aware they are seeing a cue, but unable to remember the proper response. West (2011) noted that this finding was interesting in the context of current memory research relating to episodic memory as successful encoding is often associated with slow wave activity over the frontal region of the scalp related to use of elaborative encoding strategies (Donchin & Fabiani, 1991). However, differences between PM and episodic memory literature may be due to differences in task demands, as it has been found that encoding intentions different from the ongoing activity was typically associated with a positive slow wave over the frontal region, similar to that found in episodic memory studies (Leynes et. al., 2003).

In the 2002 study conducted by West and Ross-Munroe, a difference between the amplitude of the N2 and P3 was found between older adults and younger adults. In older adults, the amplitude of the N2 and P3 was found to be greater for PM trials than ongoing activity trials, and in addition, the N2 reflected a sustained modulation over the posterior region unlike in younger adults. West (2011) hypothesized that this finding may indicate that, in contrast to younger adults, older adults engage in extended high level visual processing while encoding intentions. Furthermore, in older adults there was a slow wave over the temporal-parietal region that differed between PM hits and misses. West (2011) also noted that perhaps the finding can be explained because young and old adults may recruit different neural generators when encoding delayed intentions (West, Herndon, & Covell, 2003; West, Wymbs, Jakubek, & Herndon, 2003).

Overall, multiple studies point to the fact that three components of the ERPs are associated with PM: N300, frontal positivity, and parietal positivity (West, 2011). Both the N300 and frontal positivity are associated with the detection of PM cues, while parietal positivity represents three different components of ERPs associated with (i) the detection of a low probability target stimulus (P3b), (ii) the recognition of a PM cue (parietal old-new effect), and (iii) the configuration of the PM task set (prospective positivity) (West, 2011). In terms of the N300, what distinguishes it in ongoing activity trials from PM cues is that it reflects negatively over the occipital-parietal region beginning around 200 milliseconds (ms) after stimulus onset. In addition, the onset of the frontal positivity often corresponds to that of the N300 (West, 2011). Together these findings indicate a correlation between the N300 and frontal positivity and that both are generally related to the processing of event-based PM cues.

In terms of comparing the N300 to the N200 as West (2011) pointed out, available evidence leads to the conclusion that the N300 and N2 are due to distinct neurocognitive processes. One of the reasons leading to this conclusion is that the N300 is tied to frontal positivity, while the N200, in contrast, cannot be consistently associated with greater positivity. West (2011) suggested that the neurocognitive process reflected by the N300 as well as frontal positivity may be associated with detecting the PM cue (Einstein & McDaniel, 1996). Furthermore, the amplitude of these ERPs tends to be greater for PM misses and ongoing activity trials (West, 2007; West & Ross-

Munroe, 2002). Three studies done by West & Covell (2001), West et al. (2001) and West & Herndon et al. (2003) were also able to confirm that the N300 and frontal positivity are seen in PM lures, and thus, are a distinguishing factor between PM cues and PM lures and ongoing activity trials.

These findings demonstrate that the more similar the PM cue is with the ongoing activity trials, the more disruption of the process of cue detection associated with the N300 and frontal positivity occurs, and therefore leads to a reduction in accuracy (West, 2011). In conclusion, three important findings have been found relating the influence of strategic monitoring to the neural correlates of cue detection: the N300 and frontal positivity are limited to PM cues occurring when realization of a task is relevant to performance, failure to realize an intention can be attributed to the disruption of prospective retrieval mode, and prospective retrieval mode influences the amplitude of the N300 and frontal positivity for both focal and non-focal PM cues (West, 2011).

Parietal positivity is a sustained positivity over the parietal region of the scalp occurring between 400 and 1200 ms post stimulus, and helps distinguish PM cues from ongoing activity trials (West et al., 2001). Parietal positivity has been observed after the PM component of the task is embedded in a variety of ongoing activities (West, Herndon, et al., 2003; West & Krompinger, 2005; West, Wymbs, et al., 2003; West & Wymbs, 2004), and therefore appears to represent a process related to the realization of a delayed intention (West, 2011). As the P3b, a specific component of the positive amplitude occurring approximately 300 ms post stimulus onset that is maximal over the parietal lobe, reflects sustained positivity over the central-parietal and parietal regions, the question arose as to whether the parietal positivity elicited by PM cues is a manifestation of the P3b. Evidence, however, has suggested otherwise and that the P3b may contribute to the ERPs elicited by targets and PM cues (West, Wymbs, et al., 2003) and that prospective positivity, the maximum positive voltage elicited over the parietal lobe between 400 to 1000 ms and important with PM intention formation (Chen et al., 2015), is more limited to PM cues.

Prospective positivity has also been compared with the recognition old-new effect, or the idea that ERPs differ between newly presented stimuli compared with familiar stimuli. Evidence has been found from three different studies revealing that the recognition old-new effect and prospective positivity have distinct ERPs over the parietal region between 500 and 1200 ms post stimulus (West, 2007; West & Krompinger, 2005; West, McNerney & Travers, 2007). The study by West and Krompinger sought to compare the ERP correlates of PM with those of recognition memory, while the other two studies examined the influence of strategic monitoring on the recognition old-new effect and the prospective positivity elicited by PM cues (West, 2007; West, McNerney & Travers, 2007). The results of these studies revealed that prospective retrieval mode is not necessary in order to recognize a PM cue, a result that supports the multi-process theory of PM (West, 2011).

Differences in ERPs of Prospective Memory Throughout the Lifespan

Research conducted by West and Covell (2001) and West, Herndon, et al. (2003) revealed definite effects of aging on the N300, frontal positivity, and prospective positivity. Two of the findings from these studies are in line with the idea that the effects of aging on the N300 result from a reduction in the efficiency of controlled attentional processing. West and Covell (2001) found the reduction in amplitude of the N300 was accompanied by a reduction in the amplitude of the slow wave over the frontal region and West et al. (2003) found the amplitude of the N300 was similar for younger adults over the left and right hemispheres. In contrast, in older adults the N300 differed from ongoing activity trials only over the left hemisphere but not the right (West, 2011). That being said, a limitation exists in the literature about the effects of aging on prospective positivity, as previous research has not allowed a distinction to be made between the effects age has on the recognition old-new effect and its effects on the prospective positivity.

Previous research by West & Covell (2001) and West et al. (2003) found that the N300 is reduced in amplitude in older adults due to difficulty recruiting controlled attention processes necessary for cue detection (West & Bowry, 2005). Less consistent results have been found when examining the effect of age on prospective positivity. West et al. (2003) found age did not affect this component, while West and Bowry (2005) and West & Covell (2001) found that as individuals age the amplitude of prospective positivity decreased.

A 2007 study conducted by Zöllig et al. specifically examined the electrophysiological correlates of event-based PM across the lifespan, comparing adolescents, younger adults and older adults. The behavioral results indicated that there is an inverted U-shaped curve in PM performance with the younger adults scoring the highest. While overall performance may have been similar between the younger adult group and the older adult population, Zöllig et al. (2007) found that different processes led to the PM failures in the different groups. Error pattern analyses suggested that in adolescents the retrospective component of PM was not developed, while in older adults this component was compromised. While not statistically significant, the amplitude of the grand-averaged ERPs was highest in adolescents and lowest in older adults. Additionally, there was little difference between the amplitude of the N300 across the different age groups for the "prospective execute" trials where participants were supposed to execute the PM task. However, in "prospective inhibit" trials where a PM cue appeared, but participants were instructed not to respond, the N300 was only seen in adolescents and older adults (Zöllig et al., 2007). The prospective positivity amplitude, however, was significantly greater in adolescents compared with younger adults and attenuated in older adults compared with younger adults (Zöllig et al., 2007). Additionally, adolescents had greater activation in the precuneus and cuneus regions of the right hemisphere than younger adults for both types of prospective trials, implying adolescents may rely more on imagery to maintain the response compared with young adults. Given the differences in both behavioral and electrophysiological data between the three groups, Zöllig et al. (2007) concluded that different processes explain the PM failures in adolescence and adulthood.

Electrophysiological Correlates of Time-based vs. Event-based Prospective Memory

While a majority of EEG research examining PM has focused on event-based PM, the electrophysiological correlates of time-based PM have been found to differ in nature. A 2012 study done by Cona, Arcara, Tarantino, and Bisiacchi investigated the differences in the electrophysiological correlates related to strategic monitoring in event-based versus time-based PM cues. Strategic monitoring supports intention retrieval and consists of attention and memory processes needed to monitor the environment for PM cues. Additionally, strategic monitoring consists of both a retrieval mode, readiness to respond to the PM cue, and target checking, which is more intermittent and consists of monitoring the environment for stimuli in event-based PM or the passage of time in time-based PM. Strategic monitoring in event- and time-based PM cues is believed to be similar in retrieval mode, but different in target checking (Cona et al., 2012). Furthermore, in event-based PM tasks, individuals must constantly engage in strategic monitoring in order to detect the PM cue, while in time-based PM tasks individuals are only engaged in strategic monitoring when the time nears and they check the clock (Cona et al., 2012).

The ongoing task was the same used by Bisiacchi and collaborators in 2009 and involved a string of five letters where the letter in the first, third, and fifth positions were always the same (Bisiacchi et al., 2009). Participants were asked to determine if the letters in the second and fourth positions were the same or different. The response was a dual-task response in which participants first completed the ongoing task and then were asked to respond to the PM cue. There were two paradigms used, one time-based and the other event-based.

Behavioral results demonstrated strategic monitoring in both conditions as in both PM blocks the reaction times were slower as compared with the ongoing activity block (Cona et al., 2012). In terms of electrophysiological data, both PM tasks shared an increased positivity starting at 180 ms post-stimulus and lasting until 800 ms, broadly distributed over the scalp, but with greater incidence over the frontal and prefrontal sites. These results suggest that the ERPs elicited in time-based PM trials are still indicative of strategic monitoring (Cona et al., 2012). The similarities between the two PM blocks suggest that strategic monitoring was employed in both cases. However, there were also significant differences between the two PM tasks, suggesting that while strategic monitoring is employed in response to both types of cues, the way in which it is employed is different. The ERPs elicited in the event-based PM trials were characterized by an enhanced positivity between 400 and 600 ms post-stimulus over the parietal and occipital regions as compared with the ongoing activity trials. The same ERP modulation was not revealed in time-based PM trials (Cona et al., 2012). Therefore, as strategic monitoring is believed to differ in the target checking, this is a possible explanation for the differences seen in the ERP modulations.

Electrophysiological Correlates of Time-based Prospective Memory Throughout the Lifespan

Many behavioral studies have found that time-based PM tasks are significantly harder for individuals to perform than event-based PM tasks (Koriat et al., 1990). There have also been studies examining the electrophysiological differences of time- and event-based PM tasks (Cona et al., 2012). Additionally, multiple studies have examined both the behavioral and electrophysiological correlates of event-based PM throughout the lifespan. However, to our knowledge, no study has been performed that examines both the behavioral and electrophysiological differences in time-based PM between individuals at different ages. The aim of this study was to accomplish this goal. The MIST was used as the behavioral measure of PM examining both time- and event-based PM tasks, and was compared with the electrophysiological measures taken during a computerized task of time-based PM tasks, similar to that of Cona et al. (2012). This allowed for the comparison of the time-based measures of the MIST to the electrophysiological correlates of time-based PM and compare the electrophysiological correlates of time-based PM in individuals in different age groups to better understand how time-based PM changes with age.

Questions & Hypotheses

i. What are the specific behavioral differences and electrophysiological and correlates associated with time-based prospective memory (PM) in individuals of different ages?
    a. Younger adults will be more accurate on PM trials compared with older adults.

   b. ERP amplitudes of older adults will be reduced in electrodes located on the frontal lobe and left-hemisphere of the parietal lobe.

ii. How do the electrophysiological correlates of time-based PM correspond and compare to behavioral measures of PM?
   a. Older adults will have more PM errors in both the MIST and computer-based task as compared to younger adults.
   b. Older adults will take longer to respond to PM cues than younger adults.
   c. The PM intention trials with increased frontal activation will correlate with MIST total score.

Methods

This study took place at Trinity College in Hartford, CT and was approved by their institutional review board. The goal of the study was to investigate the relationship between clinical and electrophysiological measures of time-based PM in people of different ages. The clinical measure used in this experiment was the MIST, while the electrophysiological measures were modeled after Cona et al. (2012). In total, the experiment took approximately two hours to complete, with the MIST taking thirty minutes and the electrophysiological measure taking ninety minutes, including preparation time. All participants completed the MIST first.

Participants

A total of 16 participants were tested. Two participants were excluded from the analyses for lack of understanding of the computerized PM task. The remaining 14 individuals were split into two groups, older adults and younger adults. The 7 younger adults (M = 19.29 ± 0.36 years of age) contained of 4 females and 3 males. The 7 older adults (M = 52.00 ± 6.35 years of age) also contained 4 females and 3 males. The younger adults had mean years of education of 13.57 ± 0.30 and the older adults had mean years of education of 18.71 ± 1.51. The participants were recruited at Trinity College via emails and flyers posted throughout the campus, and consisted of students, faculty, and staff.

Inclusion criteria for healthy individuals consisted of fluency in the English language, at least twelve years of education, adequate visual and auditory functioning, and no history of neurological or psychological illness. Healthy participants were excluded if they did not satisfy the inclusion criterion and/or had significant difficulty functioning independently, had ever been diagnosed with a neurological disorder (e.g. multiple sclerosis, Parkinson's disease, epilepsy, or Alzheimer's disease), had ever been diagnosed with HIV+/AIDS, had a severe visual or auditory impairment that prevented them from engaging in daily activities, had ever received treatment for substance abuse, and/or had ever been hospitalized for a psychiatric condition. Additionally, only right-handed individuals participated, since handedness affects the hemisphere where language is processed, as there were significant differences in amplitude and latency between right- and left-handed individuals (Eskikurt et al., 2013).

All participants read and signed an IRB-approved informed consent form and were instructed that if at any point during the session they felt uncomfortable, they could leave without penalty. Both confidentiality, as well as compensation, were also addressed prior to beginning testing. Patients' confidentiality was maintained by assigning all participants with an identification number that was used on all testing forms. A demographic form was also used to collect pertinent background information including sex, race, learning and psychological diagnoses, and current medications. Participants were compensated through one of the following options of their choice: course credit (for Trinity College students), a $15 Barnes and Noble gift card, or a $15 Goldberg's gift card.

Behavioral Measure of Prospective Memory

The clinical assessment of PM was the Memory for Intentions Screening Test (MIST) (Raskin, Buckheit, & Sherrod, 2010). The MIST consists of eight PM tasks that individuals are asked to complete while working on a word search puzzle. The MIST includes both event- and time-based PM tasks after both two- and fifteen-minute delay periods. An example of a time-based task is, "In 15 minutes, tell me that it is time to take a break," and an example of an event-based task is, "When I hand you a Request for Records Form, white your doctors' names on it."

Four out of the eight tasks require verbal responses, while the remaining four require action responses. Once individuals had completed the eight PM trials, participants were asked eight retrospective multiple-choice questions about the tasks they had just been asked to complete. Finally, participants were asked to complete one final PM task with a 24-hour delay time. Participants were instructed to call the lab the next day at approximately the same time the MIST ended and state how many hours of sleep they got. Individuals could score a maximum of two points for completion of this task at the proper time. Participants received one point for completion of this task at the wrong time, or completion of an incorrect task at the correct time, and zero points if the task was not completed at all or the wrong task was completed at an incorrect time. For the 24-hour task a four-hour window (± 2 hours) was given for responses to be considered at the correct time.

On each of the eight PM tasks, participants could score a maximum of two points, with the additional possibility of scoring one point on time-based tasks. Participants would receive a score of two points if they completed the correct response at the correct time (± 1 minute), a score of one point if they completed the correct response at an incorrect time or an incorrect response at the correct time, and a score of zero points if they had no response, an incorrect response to an event-based cue, or an incorrect response at an incorrect time. In total, participants could score a maximum of 48 points on the MIST, which was calculated by taking the sum of the following eight-point subscales: 2-minute time delay, 15-minute time delay, time cue, event cue, verbal response, and action response. Additionally, individuals could earn a maximum of eight points for choosing the correct option for the retrospective recognition questions and two points for the delayed prospective memory task. In total, the MIST takes approximately thirty minutes to complete.

Electrophysiological Recording

The electrophysiological correlates of PM were examined in this study using an electroencephalogram (EEG) machine. A medium (55-59 cm) Compumedics® Neuroscan™ Quik-Cap with 64 sewn in electrodes and six external electrodes was used to collect electrophysiological data. The montage included the following scalp positions: Fp1, Fpz, Fp2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, FT8, T7, C5, C3, C1, Cz, 2, C4, C6, T8, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, CB1, O1, OZ, O2, and CB2. The computer-based task participants are asked to complete while the EEG is recording was created using Stim® 2.0 and was modeled after that of Cona et al. (2012). Participants used a marked computer keyboard to respond to visual stimuli. Right and left eye movements and blinks were recorded using four freestanding electrodes. These electrodes were placed on the side of participants' right eye and above, below, and to the side of participants' left eye. All electrodes were referenced to a reference electrode located in the center of the cap during recording. Additionally, the final two external electrodes were placed on participants' right and left mastoid bones. These electrodes recorded the base conductivity of the scalp, which was subtracted from all recordings upon data analysis.

In total, the electrophysiological portion of this experiment took approximately ninety minutes per participant to complete. Approximately thirty to forty-five minutes of this time was spent preparing the participant and cleaning up, once finished. The computer-based test, itself, then took another approximately forty-five minutes for participants to complete.

Prior to participants' arrival, the gel used to fill the electrodes was prepared. Approximately 95 mL of Compumedics NeuroMedical Supplies Quik-Gel™ was placed in a microwave-safe ceramic container. Additionally, approximately 30 mL of water was added and mixed. The mixture was then warmed in the microwave for 45 seconds.

Upon completion of the MIST, participants were escorted into the electrophysiology laboratory. First, participants were asked to wipe their forehead and around their eyes with a face wipe to prepare their skin for the electrodes. Next, subjects were asked to abrade their scalp using a sterilized wide-tooth hairbrush to allow for better impedances upon EEG recording. Upon completion, subjects' head circumferences were measured from the nose to the back of the head in order to establish proper positioning of the EEG cap. The front of the cap was then placed at a distance of approximately 10% of the head circumference above the nose.

Once the cap was in place, the six external electrodes were placed as follows: on the side of the left eye (HEOL), on the side of the right eye (HEOR), below the left eye (VEOL), above the left eye (VEOU), the left mastoid bone (M1), and the right mastoid bone (M2). All external electrodes were secured using Compumedics® v-shaped electrode washers.

The cap was then connected to the Neuroscan™ headbox, which connects to the SynAmpRt amplifier. Scan 4.5 was then used to monitor electrode impedance. The SynAmpRt amplifier had a 24-bit resolution, DC-3500Hz bandwidth and a maximum sampling rate of 20kHz. Prior to adding any gel to the electrodes, the impedance reading for all electrodes were at 50.0 kOhms. A BD 10 mL syringe with a Luer-Lok™ tip, attached to a B-D 16_G¾ blunt square grind PrecisionGlide® needle, was then filled with the conductive gel. Each electrode was then filled, starting with the reference electrode. All electrodes were insured to have impedance less than or equal to 27.5 kOhms. Once all electrodes were prepared, participants then began the computer-based task while being monitored via computer.

Computer-based Prospective Memory Paradigm

The computer-based PM task (Cona et al., 2012) consisted of an ongoing task and time-based PM cues. The computer-based PM task was programed on E-Prime® 2.0 and Stim® 2.0 and consisted of two blocks. The first block consisted of 40 trials during which participants were only asked to perform the ongoing task and was programmed using E-Prime®2.0. The second block consisted of 350 trials and participants were asked to perform not only the ongoing task, but also the PM task and was programmed using Stim® 2.0. The baseline block was administered to all participants before the PM block and instructions on the PM task were not shown until after completion of the baseline block. Additionally, during the baseline block, participants received immediate feedback on their performance.

The ongoing task consisted of strings of five white letters presented at the center of an otherwise black computer screen. The letters in the first, third, and fifth positions were always the same, while the letters in the second position were either the same or different from one another. Participants were instructed to respond via marked buttons on the keyboard with the "n" key marked "SAME" and the "m" key marked "DIFF" with either their right index finger or their right middle finger depending on whether these letters were the same or different. For example, if participants saw the following "DFDFD," they would use their right index finger to hit "SAME," whereas if they saw "DFDGD," they would use their right middle finger to hit "DIFF." Each trial began with a blank screen lasting between 1000 to 4000 ms. The strings of letters were then displayed for 300 ms or until the participant responded. After a response was given, a blank screen was shown for a variable duration such that the combined time or stimulus presentation and the second inter-trial interval was 4000 ms.

The intention formation trials used different experimental stimulus. Here, instead of seeing a string of letters, individuals were instructed to hit the red button on the keyboard (a red sticker was placed over the "z" key on the keyboard) after either two or five minutes had elapsed. Individuals were then instructed to hit the "c" key to acknowledge the understood the task. A digital clock was placed next to the computer that allowed participants to monitor the time. Responses were considered correct if the red button was hit within ±1 minute of the correct time. In total there were six time-based PM tasks embedded, three with two-minute delays and three with five-minute delays.

Electrophysiological Data Analysis

EEG was recorded using Curry7 software. All continuous EEG data was resampled at 256 Hz and then filtered between 0.1 Hz and 100 Hz. The data was then segmented into epochs starting at -3,000 ms before the onset of the stimulus and ending 3,000 ms post-stimulus. The epochs were locked to the presentation of the ongoing stimuli. Next, all epochs were digitally filtered with a low-pass 30 Hz filter. Epochs were then re-segmented to include 200 ms of pre-stimulus baseline and 1,200 ms post-stimulus activity. Next, epochs were sorted into correct and incorrect responses. Finally, epoch rejection was performed with a cutoff of ±100 µV. The computerized data was split up into eight groups depending on the time-delay, whether the intention was realized or not, and the response to the ongoing task. Additionally, the eight groups were examined at the following four time-windows: 130-180 ms, 180-300 ms, 400-600 ms, and 600-800 ms. In all time-windows the minimum and maximum amplitude was examined at all electrodes. The average amplitude was also examined at all electrodes for the following three time-windows: 275-325 ms, 550-600 ms, and 575-625 ms.

Statistical Data Analysis

All data was input into SPSS software. Paired-sample t-tests and repeated measure ANOVAs with significance level at $p<0.05$ were used to analyze MIST data. Independent-sample t-tests were used to compare average amplitudes between groups at each of the three time-windows for the following electrodes which have been previously found to be important for time-based PM: Fp1, Fp2, F3, F4, P3, P4, O1, and O2. SPSS was then used to analyze and calculate significant differences between the different age groups to help identify correlations between electrophysiological and behavioral data. Mauchly's test revealed the data violated the assumption of sphericity so within-subject effects of the computerized PM task were analyzed using the Huynh-Feldt test statistic. Bon Ferroni corrections were then run to control for significance.

Results

Memory for Intentions Screening Test

Two-tailed t-tests revealed that older adults scored significantly lower on PM tasks with a 15-minute time-delay compared with younger adults (t (12) = 2.224, p = 0.046; Figure 1). Older adults also scored significantly worse on event-based PM tasks in the MIST compared with younger adults (t (12) = 2.216, p = 0.047; Figure 1). Additionally, older adults performed significantly worse on PM tasks that required an action response compared with younger adults (t (12) = 3.216, p = 0.007; Figure 1). Total MIST scores were also significantly lower in older adults compared with younger adults (t (12) = 2.556, p = 0.025; Figure 2). Older adults scored significantly lower on the retrospective recognition (RRT) aspect of the MIST (t (12) = 3.333, p = 0.006; Figure 3). Older adults also made significantly more errors (t (12) = -2.462, p = 0.030; Figure 3) and PM errors (t (12) = -2.756, p = 0.017; Figure 3) than younger adults.

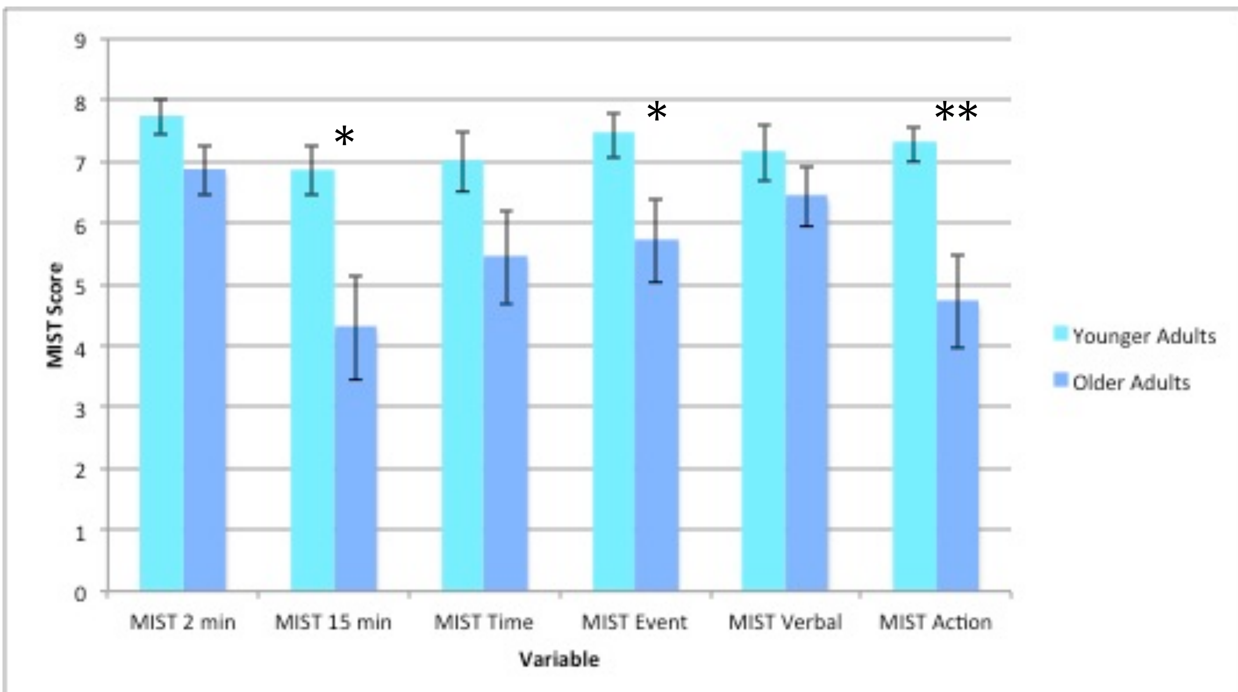

Figure 1. Mean scores on all subsections of the MIST in older and younger adults.

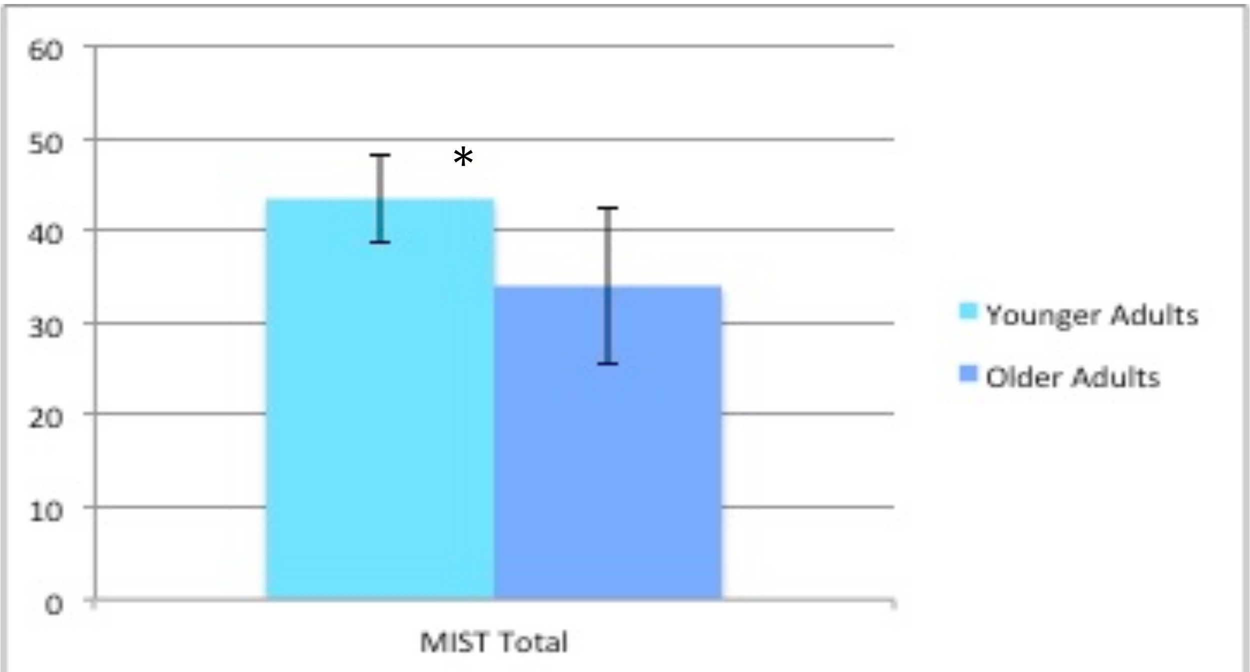

Figure 2. Older adults had significantly lower total scores on the MIST compared with younger adults (p = 0.025).

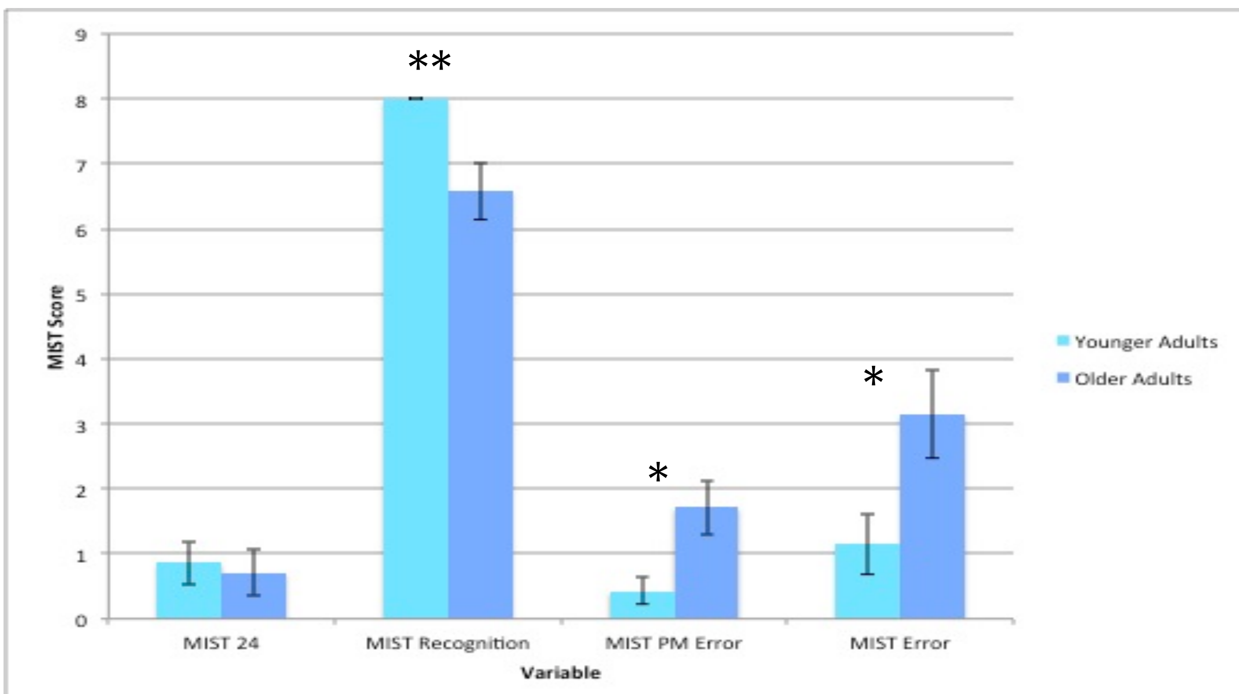

Figure 3. Mean scores on the 24-hour PM task, retrospective recognition, and number of errors in older and younger adults.

Computerized Prospective Memory Task

Two-tailed t-tests revealed that the accuracy of the 5-minute PM tasks was significantly reduced in older adults compared with younger adults (t (12) = 2.22, p = 0.046; Figure 4). Mauchly's test revealed the data violated the assumption of sphericity. Therefore, within-subject effects were examined with the Huynh-Feldt test. Results of this test showed a significant difference on accuracy scores by subject (p = 0.014). The same test revealed no significant differences when accuracy was compared between groups. Finally, pairwise contrasts indicated a significant difference between PM accuracy and accuracy on the ongoing tasks where the correct response was same (p = 0.018) and between ongoing activity trials where the correct response was same and where the correct response was different (p = 0.021) with PM accuracy being significantly lower in both cases. Between-subject effects were analyzed and showed no significant difference between younger and older adults in terms of accuracy of responses. There was however, a trend towards significance here with a p-vale of 0.051. ANOVA tests revealed no group or individual differences between reaction times on both PM hits and misses.

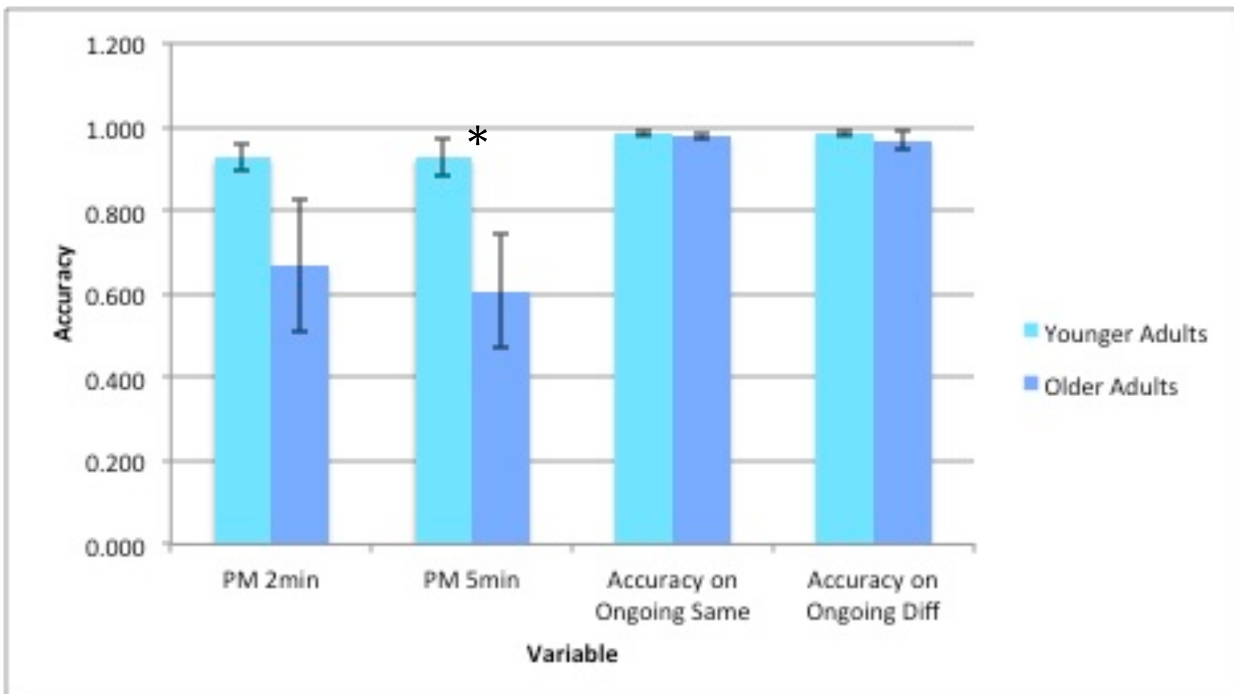

Figure 4. Accuracy on the 5-minute time-delay was significantly reduced in older adults (p = 0.046).

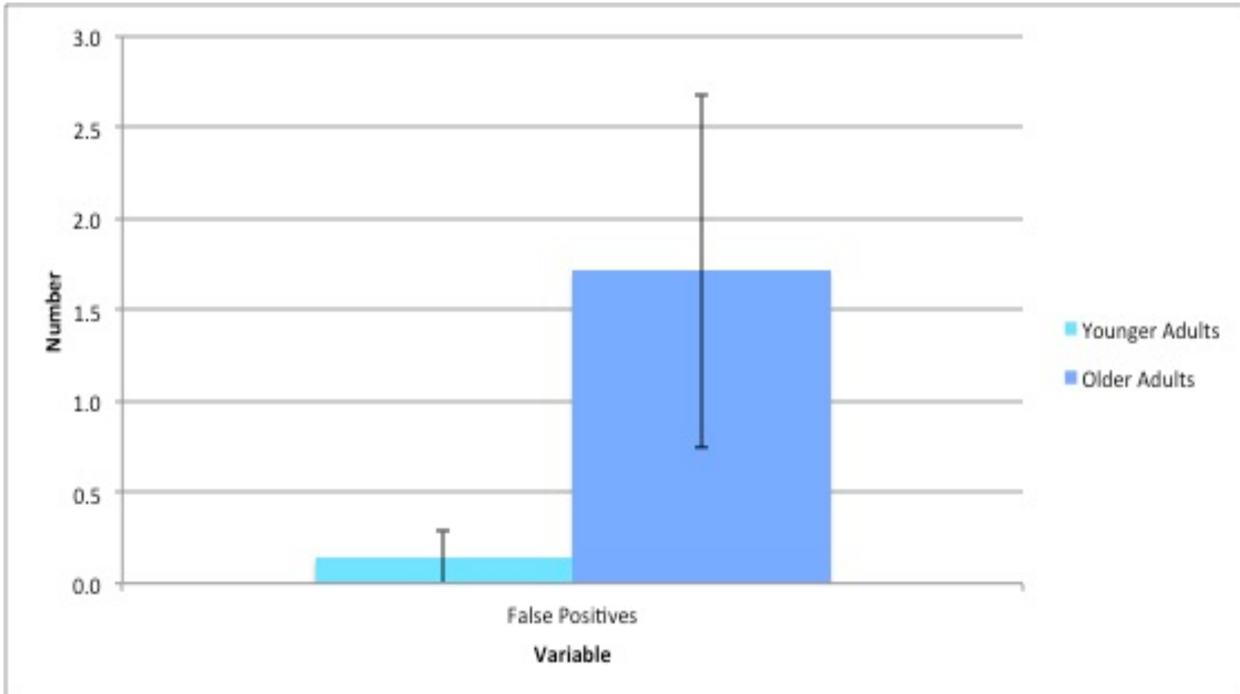

Figure 5. The number of false positives tasks was not significantly different between groups.

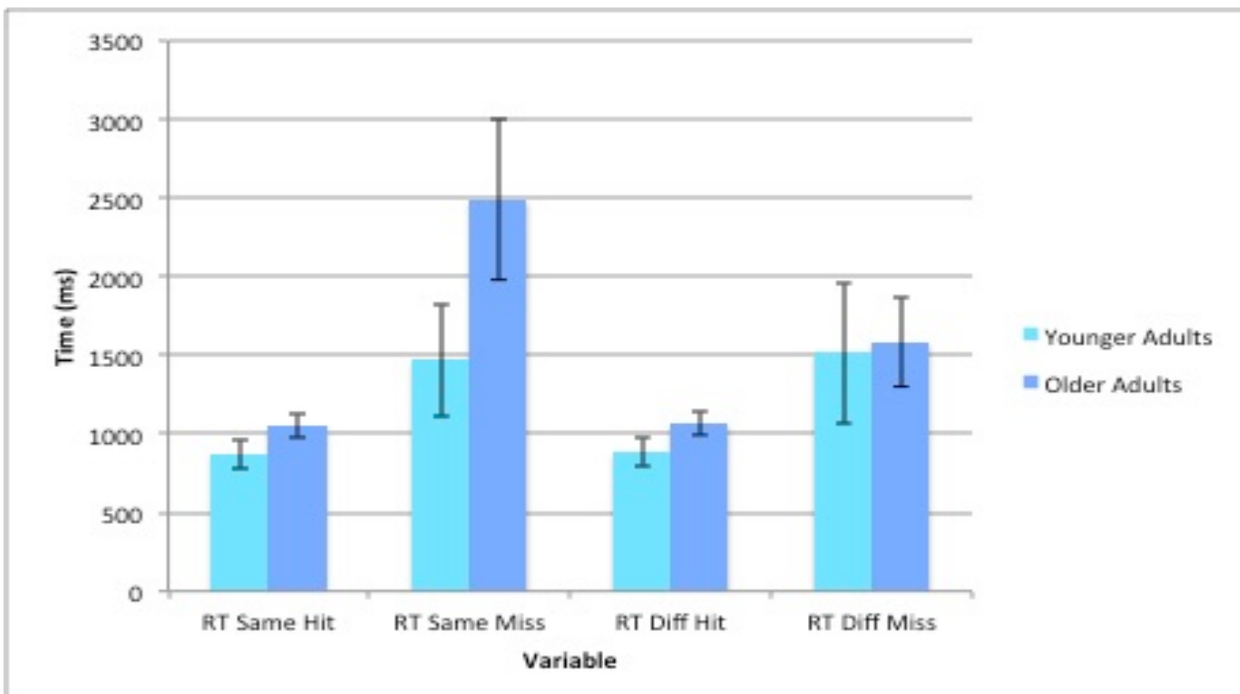

Figure 6. Reaction time on all aspects of the computerized-task did not differ significantly between groups.

Grand-averaged ERP Topography

Figures 7-10 show the differences in ERP topography between younger adults and older adults for the time-based PM condition in all four time-windows examined for realized and unrealized intentions. All figures indicate increased frontal activation in younger adults compared with older adults, especially in the early time windows, which are critical for strategic monitoring.

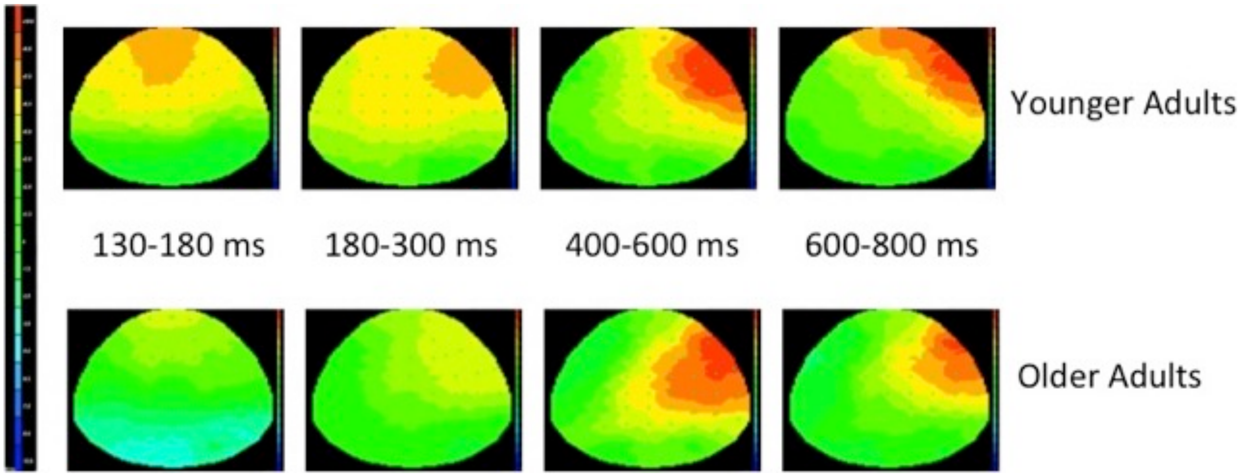

Figure 7. Scalp distribution of ERP differences in younger and older adults for realized intentions with 2-minute time delay. The amplitudes shown are obtained as differences PM block-minus-baseline block of the ERPs time-locked to ongoing trials. Average Maps are shown for the time windows in which the ERPs were analyzed.

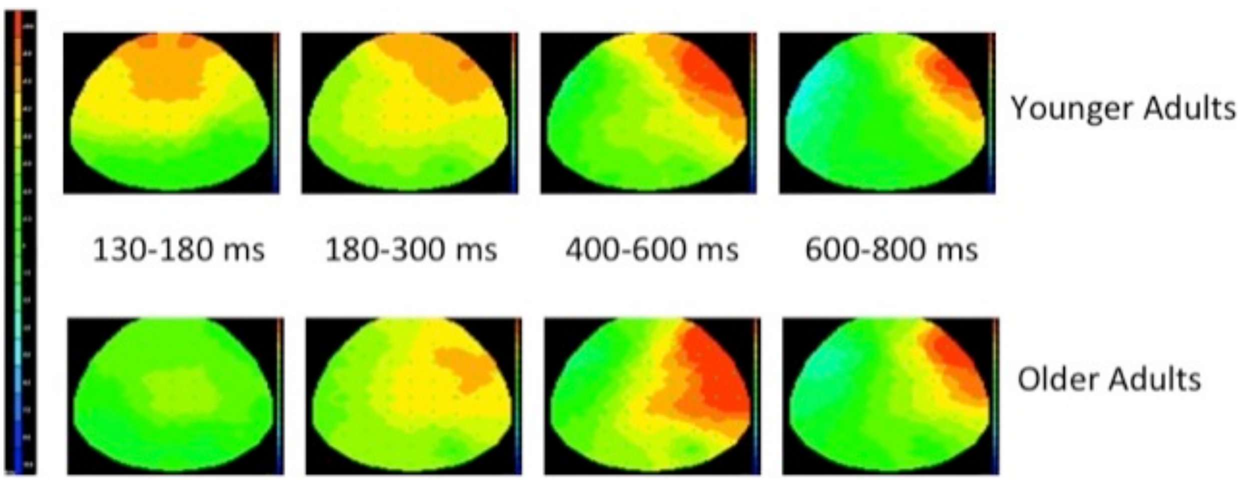

Figure 8. Scalp distribution of ERP differences in younger and older adults for unrealized intentions with 2-minute time delay. The amplitudes shown are obtained as differences PM block-minus-baseline block of the ERPs time-locked to ongoing trials. Average Maps are shown for the time windows in which the ERPs were analyzed.

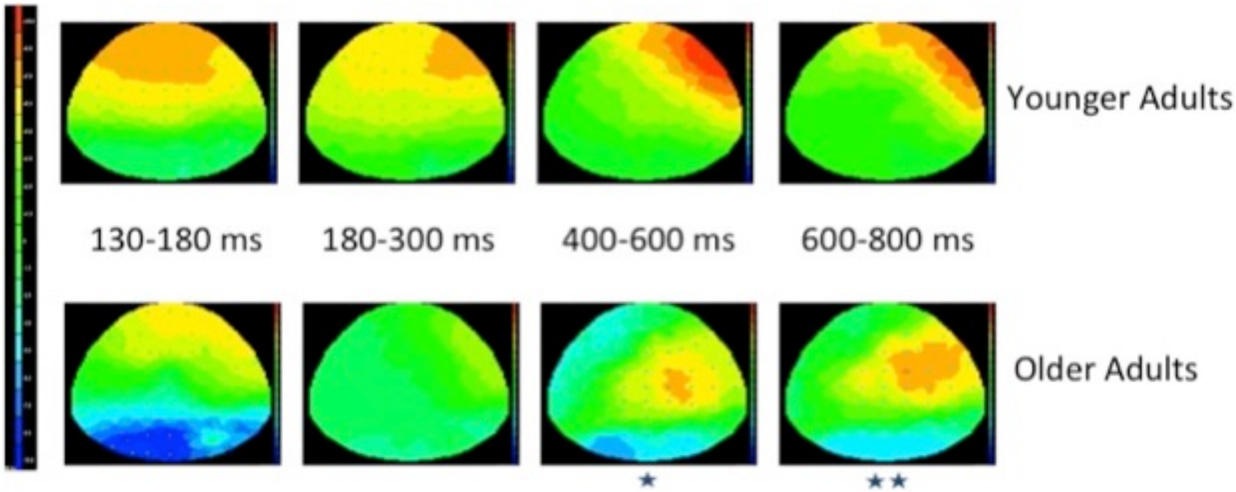

Figure 9. Scalp distribution of ERP differences in younger and older adults for realized intentions with 5-minute time delay. The amplitudes shown are obtained as differences PM block-minus-baseline block of the ERPs time-locked to ongoing trials. Average Maps are shown for the time windows in which the ERPs were analyzed. (★ scale: -5–20 µV; ★★ scale: -5–15 µV).

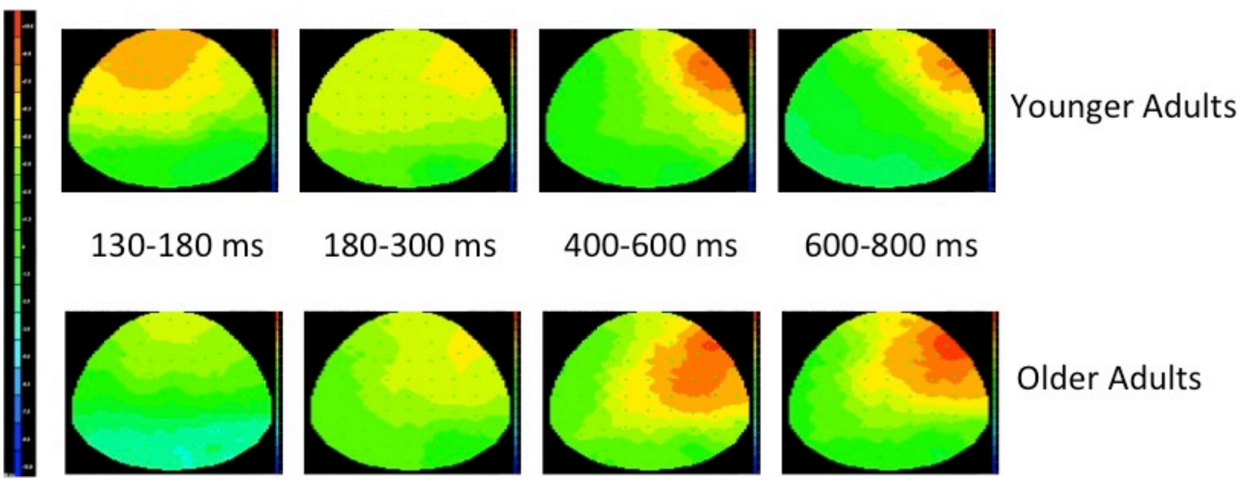

Figure 10. Scalp distribution of ERP differences in younger and older adults for unrealized intentions with 5-minute time delay. The amplitudes shown are obtained as differences PM block-minus-baseline block of the ERPs time-locked to ongoing trials. Average Maps are shown for the time windows in which the ERPs were analyzed.

Electrophysiological Data

Two-tailed t-tests revealed that older adults had significantly increased average amplitudes in electrodes Fp1 for both same (t (6) = -3.442, p = 0.014; Figure 11) and different (t (12) = -3.121, p = 0.021; Figure 11) responses and F3 for both same (t (6) = -3.602, p = 0.011; Figure 11) and different (t (12) = -3.721, p = 0.010; Figure 11) responses during the 275-325 ms post-stimulus onset time period for correctly realized 5-minute PM intentions. During this same time period, older adults had significantly reduced amplitudes in P4 (t (6) = 2.499, p = 0.047; Figure 11) and O2 (t (6) = 2.533, p = 0.045; Figure 11) electrodes for correctly realized 5-minute PM intentions for only different responses. The reduced amplitude in the O2 electrode was the only result that was sustained into the 550-600 ms post-stimulus onset time-period for correctly realized 5-minute PM intentions (t

(4.675) = 2.726, *p* = 0.045; Figure 12). All significant ERP results were seen in response to correctly realized 5-minute PM intentions.

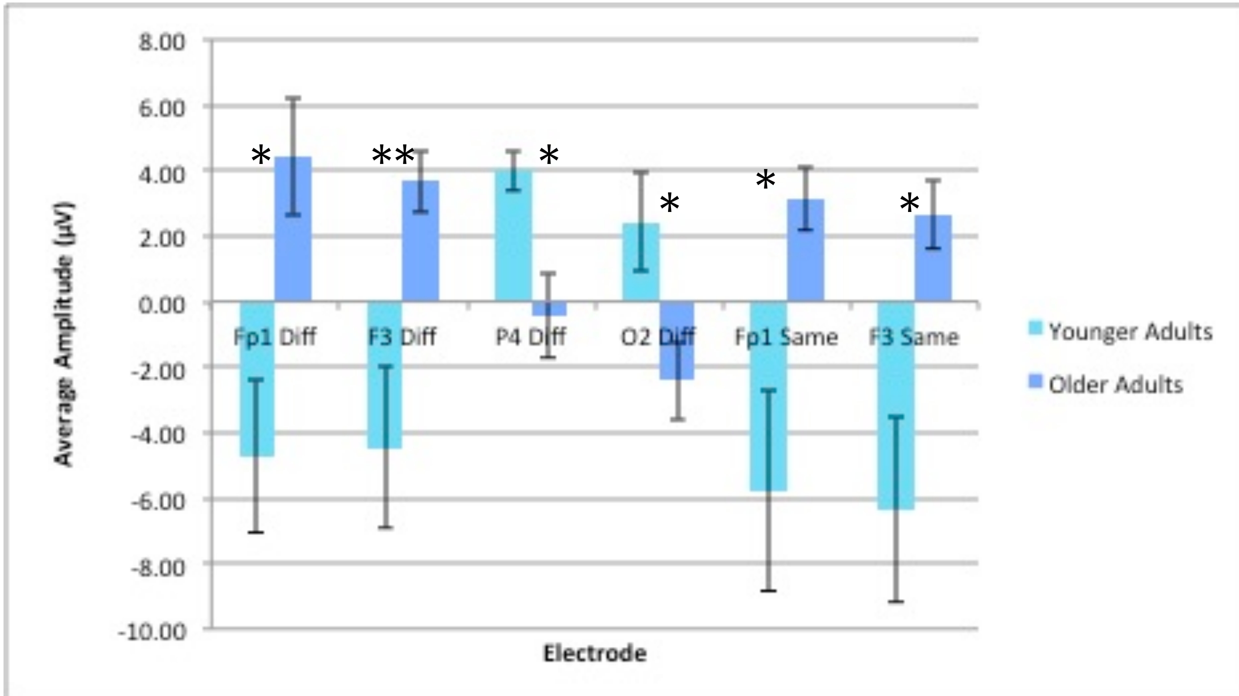

Figure 11. Average amplitude (µV) for correct responses to 5-minute PM tasks for selected electrodes for 275-325 ms.

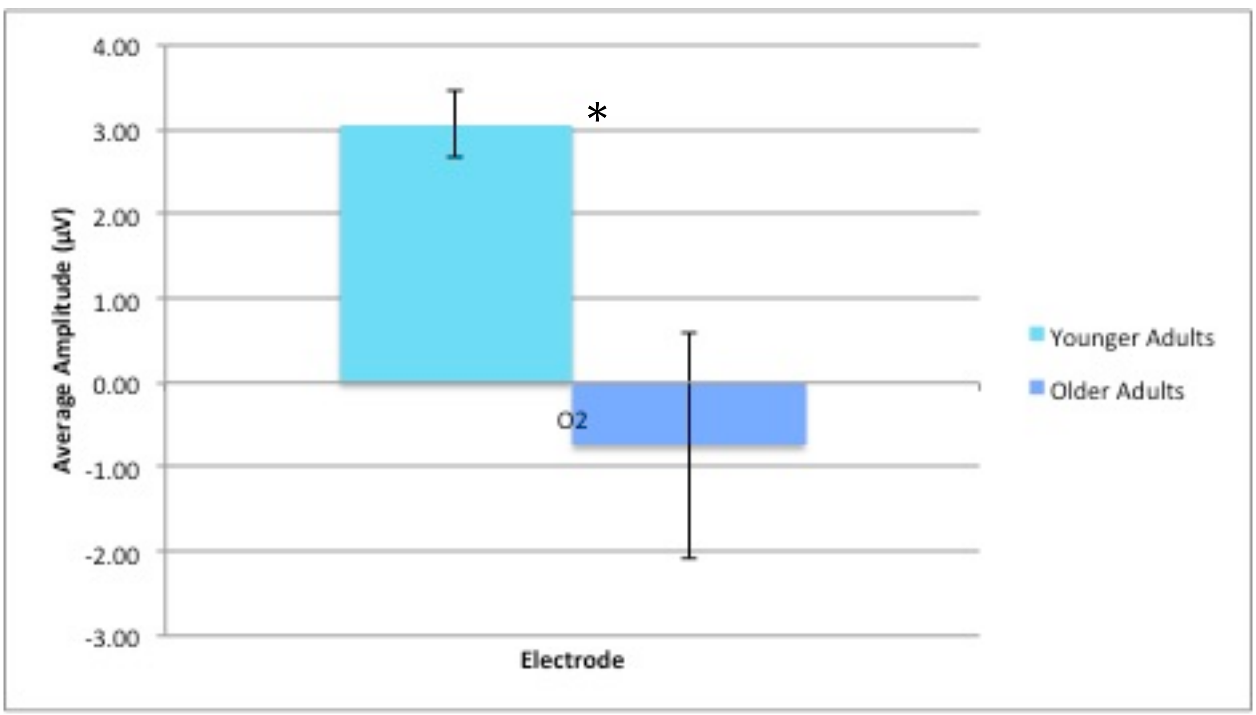

Figure 12. Average amplitude (µV) for correct responses to 5-minute PM tasks for O2 electrode for 550-600 ms.

Discussion

Significant Differences on MIST Data

Older adults performed significantly worse on MIST tasks with a 15-minute time delay, event-based cues, and action-based responses. Older adults also made significantly more PM errors compared with younger adults, which contributed to their total MIST scores being significantly lower compared with younger adults. Additionally, older adults performed significantly worse on the retrospective recognition questions, indicating a possible error in the encoding of the original PM task. These results contradict previous findings that performance on time-based PM tasks decreased with age (d'Ydewalle et al., 2001; Einstein et al., 1995; Park et al., 1997). In this study older adults performed significantly worse only on time-based tasks with a 15-minute time delay, and not on time-based tasks with a 2-minute time delay, or overall when all time-based PM tasks are considered. Thus, the 2-minute time delay may not be sensitive enough to detect age-related differences. This study also found older adults to perform significantly worse on event-based tasks, but not time-based tasks. These results contradict findings by Henry et al. (2004) who found the opposite to be true. However, event-based results have been much more inconsistent with many studies showing substantial evidence (Cherry et al., 2001; Dobbs & Rule, 1987; Kidder, Park, Hertzog, & Morrell, 1997; Mantyla & Nilsson, 1997; Maylor, 1993, 1996; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997; West & Covell, 2001) and others showing none (Einstein & McDaniel, 1990; Einstein et al., 1995). Additionally, older adults performed significantly worse on action-based responses compared to younger adults, suggesting possible deficits in the mechanism necessary for performing these types of tasks in older adults. While it had been previously found that older adults had more trouble with PM tasks compared with retrospective ones (Henry et al., 2004), this study found that in addition to PM deficits, older adults performed significantly worse on retrospective recognition questions compared with younger adults. This paired with the finding that older adults made significantly more PM errors suggests that they may not have properly encoded the intention. These results support McDaniel and Einstein's (2002) multi-process framework theory of PM. This suggests that the method used to realize a PM intention depends on multiple factors. Older adults were seen to have more difficulty in specific subsections of the MIST, possibly indicating that they viewed these as less important and thus, did not devote as much of their diminished resources to these tasks. For example, a possible explanation that is in line with this theory is that participants knew the goal of the study was to examine time-based PM specifically and thus, may have viewed these tasks on the MIST as more important.

Given the novel and unexpected findings, this study should be repeated with a larger sample size. Additionally, the age range for the older adult group was much larger than that of the younger adult group, so a smaller age range should also be examined. The standard error of the age of the younger adult group was 0.36 compared with 6.35 for older adults. Another possible explanation is that the older adults had significantly more years of education compared with the younger adults, adding another variable (t (6.466) = -3.347, p = 0.014).

Significant Differences on the Computerized PM Task

The only aspect of the computerized PM tasks that differed significantly between groups was on the accuracy of the PM tasks with a 5-minute time delay. When considered with the MIST results, this indicates that while a 2-minute time delay may not be a sensitive enough, a 5-minute time delay is long enough to notice differences due to age. These results suggest that the longer the time delay, the harder the task is for older adults to correctly perform. There were no other significant differences seen in the computerized PM task both in terms of accuracy and reaction time. A possible explanation for this is that because the clock was not time-synced with the program, a large window of ± 1 minute had to be accepted for correct PM responses.

Overall ERP Findings

The only significant ERP differences were seen in response to realized 5-minute PM intentions. Thus, regardless of the time delay when both older and younger adults failed to realize a PM intention, there was no difference. In other words, neither group was aware they were failing to execute an intention. MIST results suggested that older adults may not be properly encoding the PM intention. However, those results were for a combination of both event- and time-based PM tasks and there is no retrospective portion of this task to know whether the same is occurring. Given that both younger and older adults looked the same electrophysiological for unrealized intentions, however, suggests that there is not a difference in how they are failing to execute the task. Additionally, the fact that the electrophysiological differences were only seen in realized 5-minute PM intentions and not in realized 2-minute PM intentions indicates that the process of realizing and/or maintaining an intention for a longer period of time may be different than that necessary for a shorter time delay. This difference in mechanism may help explain why older adults had significantly lower accuracy on the 5-minute PM tasks, but not on the 2-minute PM tasks.

Significant ERP Differences in 275-235 ms Post-stimulus Time Window

The only significant ERP differences seen between groups were for realized 5-miunte PM intentions. In the 275-325 ms post-stimulus time period, older adults had significantly higher average amplitudes in left frontal electrodes. Conversely, during this same time period, older adults had significantly reduced average amplitudes in right parietal and occipital electrodes. This time window is important for strategic monitoring. Thus, these results indicate that the frontal lobes of older adults may require greater activation in order to maintain the intention in PM tasks with a 5-minute time delay. The cost of this increased focus on maintenance of the intention was seen in the significantly reduced amplitude in the right parietal and occipital electrodes.

The negative waveform seen in younger adults at electrodes Fp1 and F3 is consistent with the findings of Cona et al. (2012). There are two possible explanations for the positive waveforms seen in these electrodes in the older adults. The first is that the waveform may be delayed in older adults. Cona et al. (2012) found a positive waveform to occur in both Fp1 and F3 electrodes in the time period from 150 - 275 ms post-stimulus onset in time-based PM. The waveform neutralizes after 500 ms, which would help explain why this time period was the only one examined where significant differences were found between groups. Another possible explanation is that given the external nature of the clock, older adults responded to the time-based PM task as an event-based PM task. In the computerized paradigm in Cona et al. (2012), participants could view the elapsed time on the computer screen in place of the string of letters. Alternatively, in the present study, the clock was external and thus, more of a visual stimulus to be processed.

The reduction in the average amplitudes in older adults at the parietal and occipital electrodes also supports either of these hypotheses. However, the electrodes were the corresponding electrodes in the right hemisphere, to those found in the left hemisphere in the Cona et al. (2012) study. This contradicts our hypothesis that older adults would have reduced amplitudes in electrodes in the left hemisphere compared with younger adults. This hypothesis was formed based on a study by West (2011) that found electrodes in the left-hemisphere to be specifically altered with age. While more research is needed to determine why we only saw differences in the right hemisphere and not the left, a possible explanation for the negative average amplitude seen in older adults in comparison with the younger adults is that again, the waveform was delayed. Cona et al. (2012) found that in electrodes P3 and O1, there was a negative amplitude prior to the positive waveform seen during the timeframe examined. While, it is also possible, that again the external nature of the clock, made the time-based cue an event-based one, this is less likely. The West (2011) study only examined event-based PM. To our knowledge, no study has examined the electrophysiological correlates of time-based PM in older adults. Thus, when taken together with our results, it appears that electrophysiological changes with age for event-based tasks occur in the left hemisphere, while changes for time-based tasks are seen in the right hemisphere.

Significant ERP Differences in 550-600 ms Post-stimulus Time Window

Again, the only significant ERP differences seen between groups were for realized 5-miunte PM intentions. The only significant difference that persisted from the first time window to the second, was the significant reduction in average amplitude of O2. Specifically, this time frame is important for detection of the cue. Thus, the negative amplitude indicates that the occipital lobes of older adults were working harder to detect the cue than those of younger adults who exhibited positive average amplitudes in this timeframe. This result is interesting because it suggests that the external clock acted as more of a visual stimulus, as this result was only seen in event-based PM trials in the Cona et al. (2012) study. However, given that the results from the 275-325 ms suggest the possibility to a delayed waveform, that option was also examined to explain the results seen here. Upon further examination, a delay does not explain the negative waveform here. Thus, given that this pattern was seen in event-based PM previously (Cona et al., 2012), and this time window is important for cue detection, the results suggest that the external nature of the clock allowed it to act as a visual stimulus for older adults given the occipital activation.

Lack of Significant ERP Differences in 575-625 ms Post-stimulus Time Window

No significant differences were expected in this time window given that as more time passes after stimulus onset, the waveform begins to attenuate towards zero. This is true in both time- and event-based PM. These results are consistent with the Cona et al. (2012) study, which found no specific electrode differences in this time frame for either time- or event-based PM.

Conclusion

Overall, this study provides the first evidence of electrophysiological changes associated with aging in time-based PM. The hypothesis was supported that younger adults would be more accurate on PM trials compared to older adults. In the MIST younger adults performed significantly better on tasks with a 15-minute time delay, event-based cues and action-based responses. Additionally, on the computerized PM tasks, younger adults performed significantly better than older adults on tasks with a 5-minute delay period. The hypothesis that older adults would make more PM errors in the MIST and computer-based task was only partially supported. Older adults made more PM errors and overall errors on the MIST, but there were no significant differences on the computer-based task. A possible explanation for this is that because the clock was not time-synced with the program, a large window of ± 1 minute had to be accepted for correct PM responses. The hypothesis that older adults would take longer to respond to PM cues than younger adults was rejected, as none of the reaction time data was statistically significant. The hypothesis that PM intention trials with increased frontal activation would correlate with MIST total score was supported as younger adults were seen to have increased frontal activation in realized and unrealized intentions for both 2- and 5-minute time delays and had significantly higher MIST total scores compared with older adults. Finally, the hypothesis that ERP amplitudes of older adults would be reduced in electrodes located on the frontal lobe and left-hemisphere was not supported as the opposite was seen in both cases. However, the ERP results varied by hemisphere, as had been previously seen by West (2011), but the results for time-based PM were seen in the opposite hemisphere than expected.

Future Directions

A larger sample size is needed to further verify these results. Additionally, more research should be conducted into the effects of having an external clock versus one that appears on the screen in place of the ongoing task. There was some indication that the external clock may have served as a visual stimulus, especially for older adults, thus altering the conditions for traditional time-based PM. Another issue that arose from the external clock was that since it was not time-synced with the PM task a generous window of ±1 minute had to be accepted for correct PM responses. Finally, given that behavioral studies have found that time-based PM is more sensitive to effects of brain disorders and injuries (Raskin, 2009), this study could be applied to a more clinical population to determine if there are electrophysiological differences specifically in time-based PM, that may not be seen with event-based PM.

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